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CORUNDUM CERAMICS BASED ON ALUMINUM OXIDE OBTAINED BY A PLASMA CHEMICAL METHOD

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Problems of sintering aluminum oxide consisting of highly disperse α - Al_2O_3 prepared by the plasma chemical method are considered. It is shown that this material possesses high sinterability even in the case of considerable pressing pressures. The introduction of MgO improves sintering of plasma chemical aluminum oxide and the addition of partially stabilized zirconia increases the ultimate strength of the ceramics in three-point bending to 450 MPa.

The modern state and development of ceramics technology and primarily the technology of high-grade powders, both of the initial material and additives, and sintering theory shows that the possibilities of creating new kinds of ceramic materials based on oxides and their compounds, including aluminum oxide, have not been exhausted. The development of new technological solutions and principles for choosing the additives promotes the creation of novel materials and widens their application range.

As a rule, the most important properties of ceramic articles are determined by the microstructure and phase composition of the material which depend, in turn, on the structure of the initial powder, the kind and distribution of the additive, the firing regime and the sintering mechanism. Today the most promising structural materials in many fields of engineering are poreless ones with a fine crystalline and homogeneous structure.

Ceramics with low porosity and fine crystals of approximately the same size can be obtained from highly disperse unaggregated single-fraction powders. Such powders are produced using special chemical methods [1–3] with control of their synthesis in order to eliminate the formation of coarse and strong aggregates.

High dispersion of the powders can be provided by various methods. The plasma chemical method which gives single-fraction powders with a small particle size can be used for this purpose. Powders synthesized in this way are comparatively new in the ceramics industry and are used, for example, for the production of silicon nitride ceramics [4]. Plasma chemical powders of oxides used as the initial material for production of ceramics have virtually not been studied and no published data on this topic can be found.

In the present work, we studied the problem of manufacturing high-density corundum ceramics from a highly disperse alumina powder synthesized by plasma chemistry. In accordance with the data of an x-ray phase analysis, the alumina was represented by an α - Al_2O_3 crystal structure and an inconsiderable amount of γ - Al_2O_3 . It followed from the results of a petrographic and electron-microscopic study that the plasma chemical alumina powder was highly disperse and had a mean particle size of 0.3 μm . The powder was fully disaggregated.

Since the material had very high dispersion, it was very important to obtain quite dense preforms from it. The specimens were pressed at 100 MPa and subjected to additional compression in a hydrostat at 200–1000 MPa. The effect of the pressing pressure on the properties of the ceramics was studied on rods $40 \times 6 \times 4$ mm in size. The temporary technological binder was a 2.5% solution of polyvinyl alcohol introduced into the batch in the amount of 20% (here and below, in mass fractions).

The shaped specimens were fired in air and in a vacuum at 155°C with 2-h holding. The results are presented in Table 1. It can be seen that the mean density of the preforms increases with an increase in the pressure. The highest mean density of the fired specimens was 3.62–3.67 g/cm³ for open porosity of 4%. The specimens did not sinter to zero open porosity, even when treated with intermediate holding and pressed at very high pressure. The structure of the specimens was characterized by intense recrystallization with growth of the crystal to 15–20 μm when the firing was conducted in air and to 25–30 μm when it was conducted in a vacuum, and by the formation of quite coarse (up to 10 μm) inter- and intracrystalline pores. The ultimate strength in three-point bending was about 250 MPa.

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TABLE 1

| Pres- sure, MPa | Density of preform, g/cm ³ | Density, g/cm ³ | | Open porosity, % | Linear shrinkage, % | Bending strength, MPa |
|--------------------------|---|----------------------------|-------------|------------------------|---------------------------|-----------------------------|
| | | apparent | relative | | | |
| 100 | 1.86 | <u>3.56*</u> | <u>89.4</u> | <u>3.80</u> | <u>16.5</u> | <u>210</u> |
| | | <u>3.53</u> | <u>87.7</u> | <u>4.02</u> | <u>15.5</u> | <u>170</u> |
| 200 | 1.96 | <u>3.62</u> | <u>91.0</u> | <u>3.60</u> | <u>17.5</u> | <u>220</u> |
| | | <u>3.55</u> | <u>89.2</u> | <u>4.10</u> | <u>16.5</u> | <u>180</u> |
| 500 | 2.07 | <u>3.67</u> | <u>92.2</u> | <u>3.20</u> | <u>18.0</u> | <u>250</u> |
| | | <u>3.58</u> | <u>90.0</u> | <u>4.00</u> | <u>16.7</u> | <u>200</u> |
| 1000 | 2.12 | <u>3.60</u> | <u>90.5</u> | <u>3.70</u> | <u>17.0</u> | <u>190</u> |
| | | <u>3.60</u> | <u>90.5</u> | <u>4.90</u> | <u>17.0</u> | <u>160</u> |
| <i>0.3% MgO additive</i> | | | | | | |
| 100 | 1.86 | <u>3.56</u> | <u>89.4</u> | <u>3.50</u> | <u>16.5</u> | <u>210</u> |
| | | <u>3.64</u> | <u>91.6</u> | <u>3.20</u> | <u>17.8</u> | <u>220</u> |
| 200 | 1.96 | <u>3.75</u> | <u>94.2</u> | <u>3.00</u> | <u>19.0</u> | <u>230</u> |
| | | <u>3.77</u> | <u>94.7</u> | <u>3.00</u> | <u>19.0</u> | <u>240</u> |
| 500 | 2.07 | <u>3.82</u> | <u>96.0</u> | <u>2.20</u> | <u>19.7</u> | <u>260</u> |
| | | <u>3.83</u> | <u>96.2</u> | <u>2.10</u> | <u>19.7</u> | <u>270</u> |
| 100 | 2.12 | <u>3.85</u> | <u>96.7</u> | <u>1.80</u> | <u>20.0</u> | <u>300</u> |
| | | <u>3.86</u> | <u>97.0</u> | <u>1.50</u> | <u>20.0</u> | <u>310</u> |

* The data in the numerators are given for firing in air; the data in the denominators are given for firing in a vacuum.

In order to create high-density alumina-based materials with a high level of properties, it is virtually always necessary to use additives for modifying the structure of the ceramics. A known additive to alumina is magnesium monoxide [5–7] which has been used for creating such corundum-base materials as polycor, microlite, and sapphirite.

Density close to the theoretical value is commonly attained by using from 0.07 to 0.3% MgO [8]. The additive forms a solid solution with the aluminum oxide, promoting the appearance of isometric crystals and improving substantially the properties of the material.

The introduction of 0.3% MgO into plasma chemical aluminum oxide and the use of hydrostatic pressing provides for fuller sintering of the specimens and uniform crystallization with a crystal size of 10 μm after firing at 1550°C. The ultimate strength of the specimens in three-point bending attains about 300 MPa (see Table 1).

Ceramic materials based on alumina and containing up to 50% partially stabilized zirconia (PSZ) have drawn much interest in recent years. Such materials are characterized by high strength, fracture toughness, and wear resistance parameters. Zirconia is introduced into the compositions in the form of a tetragonal modification that provides for strengthening due to phase transformation. It was noted in [9, 10] that addition of up to 40% PSZ in a corundum matrix provides for high ultimate strength in three-point bending (up to 800 MPa) and high recrystallization resistance at a high temperature.

In order to increase the strength of the ceramics, plasma chemical alumina containing 0.3% MgO was additionally enriched with 20 and 40% PSZ prepared by the method of chemical precipitation. The powders were plasticized by a 2.5% solution of polyvinyl alcohol added in the amount of

TABLE 2

| Firing temperature, °C | Mass fraction of additive, % | Properties of specimens | | | |
|------------------------|------------------------------|-------------------------------------|------------------|---------------------|-----------------------|
| | | apparent density, g/cm ³ | open porosity, % | linear shrinkage, % | bending strength, MPa |
| Firing in air | | | | | |
| 1550 | 20 | 4.09 | 0.8 | 20.0 | 380 |
| | 40 | 4.69 | 0.3 | 24.0 | 400 |
| Firing in vacuum | | | | | |
| 1600 | 20 | 4.25 | 0.4 | 23.4 | 420 |
| | 40 | 4.70 | 0.1 | 25.2 | 460 |

1% per dry substance. The specimens were pressed at 100 MPa and fired at 1550°C in air and at 1600°C in a vacuum with 2-h holding (Table 2).

The density and the strength of corundum ceramics increase with the amount of additive. The increase in the strength is connected with a decrease in the size of the corundum crystals and the presence of PSZ. With introduction of 40% PSZ the material possesses a fine crystal structure with a mean crystal size of 2 μm . The phase of tetragonal zirconia is distributed uniformly over the boundaries of the corundum crystals in the form of layers less than 1 μm thick. The ultimate strength in three-point bending is about 450 MPa, but this is lower than in specimens fabricated from chemically precipitated powders.

Thus, the use of plasma chemical alumina as a raw material for corundum ceramics is not expedient because the level of the properties of such ceramics does not exceed the parameters of materials based on commercial alumina. Plasma chemical alumina seems to be applicable in low amounts as an additive to various materials to control processes of formation of the microstructure.

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